IMPROVING SURFACE IRRIGATION DESIGNS AND MANAGEMENT PRACTICES IN THE IMPERIAL VALLEY, CALIFORNIA

Prepared By

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ANTECENDENTS

In 2002 Natural Resources Consulting Engineers, Inc. (NRCE) presented an assessment of Imperial Irrigation District's (IID) reasonable and beneficial use of water. The analysis was supported by ten evaluations of fields served by IID[2]. The evaluations employed a standard methodology designed to produce estimates of irrigation efficiency and uniformity[3]. This methodology is used to evaluate the effectiveness of existing irrigation practices as well as in estimating the potential efficiencies and uniformities which result from improvements in the field design and water management practices. The NRCE report contains a summary of the evaluation data and an estimate of existing irrigation efficiencies, but it does not consider changes in either design or management that would increase efficiencies or uniformities.

In November 2002, the writer began a review NRCE field evaluation data, as well as other data being collected from farms in the IID service area, to extend the NRCE analyses to estimates of potential irrigation efficiency and uniformity. This report summarizes a series of computations using a surface irrigation simulation, evaluation, and design software package abbreviated as ***SIRMOD III***[4]

METHODOLOGY AND SCOPE

The ***SIRMOD III*** program is based on generally published procedures and algorithms for simulation, design, and evaluation of surface irrigations systems. It is a comprehensive software package for simulating the hydraulics of surface irrigation systems at the field level, selecting a combination of sizing and operational parameters that maximize application efficiency and a two-point solution of the "inverse" problem allowing the computation of infiltration parameters from the input of advance data. The software was used to evaluate the potential efficiency and uniformity of selected fields in the IID service area that NRCE has evaluated as well as one farm evaluated by a MWD consultant[5]. The analysis presented herein involved the following steps:

1. A "reconstruction" of the data was made for the ten field evaluations presented in the NRCE report. The NRCE report presents a summary of most but not all results of their analyses. In order to evaluate the impact of improved design or water management practices, it was first necessary to calibrate ***SIRMOD III*** to the average data presented by NRCE. The results of this reconstruction allow software to simulate the irrigations of a field typical of those studied by NRCE.
2. Following calibration of the simulation portion of the software, a series of redesigned field options were evaluated to determine the extent of improvements that might be

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[1] Utah Registration No. 152758-2202.

[2] Natural Resouces Consultanting Engineers, Inc. 2002. Assessment of Imperial Irrigation District's Water Use. Report and Appendices. March.

[3] Merriam, J.L. AND Keller, J. *Farm irrigation system evaluation: A guide for management.* 1978. Department of Biological and Irrigation Engineering, 4105 Old Main Hill, Logan, Utah, 84322-4105

[4] Walker, W. R. 2003. "***SIRMOD III*** – Surface Irrigation Simulation, Evaluation, and Design. Guide and Technical Documentation. Biological and Irrigation Engineering. Utah State University, Logan, Utah. 146p.

[5] Declaration of Harold Payne in Opposition to IID's Motion for Preliminary Injunction.

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possible in both uniformity and efficiency. Each redesign was evaluated with revised water management practices in order to optimize the use of water on the field.

3. A comparison of existing field performance as measured by NRCE and projected performance estimated by the software was used to estimate water savings possible through redesign of the existing systems.
4. The performances of the on-farm components of the irrigation system are sensitive to the management of the IID delivery network. A single analysis was made to illustrate the problem of delivery management on the efficiency and uniformity of the farm irrigation system.
5. The spatial distribution of leaching fractions was examined for nine of the ten NRCE field sites under measured and redesigned conditions.
6. An analysis of one additional field evaluation conducted by Payne for MWD was conducted with the software to extend the conclusions of the writer somewhat beyond the scope of the NRCE analyses.

Nine of the ten field evaluations reported by NRCE involved graded borders which are used locally to irrigate alfalfa, Sudan and Bermuda grass, etc. One field was furrow irrigated (Field 8) but was growing alfalfa at the time of the study. These conditions are estimated to represent about 50% of the irrigated area in the IID system. All of the evaluations were preceded by earlier watering and thus represent a mid-season condition for the fields studied. The Field 10 irrigation was being used for a special leaching application and has not been examined beyond the initial calibration. The data collected by Payne represented the case of a different soil being irrigated earlier in the season.

TECHNICAL NOTES

In describing the infiltration characteristics of the fields evaluated, NRCE notes the dependence of intake rate on initial soil moisture and surface cracking. They subsequently assign a portion of the water added to the crop root zone to the cracks. Expressed in this fashion, the cracks would act similar to depression storage on the field surface. However, the cracks vanish during the irrigation as the soils swell, and thus, whatever initial volume of water is needed to fill the cracks during the advance of water over the field is likely "given back" when the cracks close. A more likely consequence of the cracks is they substantially increase the contact area of the field for a short period during the irrigation, and thus, most of the water added to the root zone via cracks is due to normal infiltration processes within a temporarily increased contact area. The results of the calibration analyses indicate that special considerations of soil cracking in terms of depression storage are not necessary.

NRCE also presents their estimates of the "intake rate after initial infiltration (in/hr)". The values presented are more typical of silty loam soils rather than the clay and clay loam soils encountered in the fields evaluated.

NRCE appeared to state that measurements of surface storage during the advance allowed them to estimate the soil intake characteristics, but none of this information was reported. Consequently this work is based on simulations made using the NRCE data on advance times, set times, tailwater volumes, and root zone storage depths to establish conditions of a similar nature to those reported.

CALIBRATION RESULTS

Results of the ten ***SIRMOD III*** calibrations are presented in Table 1 alongside NRCE reported results.

TABLE 1. COMPARISON OF ***SIRMOD III*** AND NRCE EVALUATIONS FOR TEN IID FIELD SYSTEMS.

1	258-276	*304*	28	*27*	68	*70*	3	*3*	72	*73*	*97*
2	216-240	*238*	14	*14*	84	*83*	3	*3*	87	*86*	*92*
3	720	*735*	13	*13*	82	*82*	5	*5*	87	*86*	*89*
4	258-318	*315*	0	*0*	80	*80*	20	*20*	85	*86*	*74*
5	2010-2100	*1880*	6	*6*	78	*77*	17	*17*	87	*83*	*85*
6	408-444	*486*	12	*13*	80	*79*	9	*8*	88	*85*	*94*
7	474-480	*495*	19	*19*	76	*76*	5	*5*	80	*80*	*92*
8	180-210	*169*	20	*20*	76	*75*	5	*5*	80	*79*	*93*
9	570-600	*490*	20	*21*	78	*76*	3	*3*	80	*79*	*97*
10	3 days	*22.5 hrs*	0	*2*	48	*56*	37	*41*	N/A	*61*	*99*

[6] Root Zone Storage is the same as the term "application efficiency" used in irrigation literature.

[7] NRCE Irrigation Efficiency is the Root Zone Storage percentage plus a 2% - 8% value for leaching fraction. How the leaching fraction was determined is unclear.

[8] The ***SIRMOD III*** software estimate of irrigation efficiency is the root zone storage plus up to 8.5% leaching fraction as suggested by Rhoades and divided by the total applied water to the field, including tailwater. The uniformity of leaching is such that even though an average leaching fraction on a field might average 8.5%, some areas might receive more, resulting in excessive deep percolation, and the actual leaching fraction added to the root zone storage would be less.

ANALYSES OF SELECTED ON-FARM WATER MANAGEMENT IMPROVEMENTS

Return flows from the irrigated fields of the IID service area are comprised of tailwater and drainage (a component of which is tilewater). About one-half of the local soils have low infiltration characteristics, and thus given the need for leaching of salts, the opportunities for water management and conservation necessarily emphasize tailwater contols. The NRCE report estimates that field tailwater in the IID service area averaged 17% of headgate diversions during the period 1988-1998. Electronic records from 288 irrigation events during the 2001 year indicate an average tailwater percentage of about 15%. Tailwater is highly variable depending on irrigator skill, water management practices, system design, and delivery rates from the IID canal and lateral system. During 2001, for example, tailwater losses ranged from 0-46%. The average tailwater losses from the ten fields evaluated by NRCE were nearly 15% (excluding Field 10 for reasons noted above). Therefore, fairly consistent estimates of the average tailwater volume have emerged from NRCE analysis and IID monitoring.

There are three primary tailwater control strategies: (1) blocking the end of the fields to prevent runoff; (2) capturing the runoff and reusing it. (Both of these strategies are already found in the IID service area).; and (3) terminate the inflow soon enough to eliminate or minimize the tailwater. The third option will generally result in inadequate watering and leaching at the lower end of the field, and while it is an alternative, it does not appear to this writer to be realistic over the long term.

The impact of widespread tailwater capture and reuse will not be detailed here beyond what is easily determined. If tailwater now occurring were collected and reused, the headgate diversions per acre could be reduced accordingly.

Diking the end of the field to prevent tailwater runoff is a common practice through the western U.S. and could be implemented in the IID service area with limited modifications to existing furrow and border irrigation systems. The IID monitoring in 2001 shows that while the likelihood of field tailwater exceeding five percent of headgate diversion is 80%, one in five fields (20%) had less than five percent tailwater. Given the importance of water in Southern California and the conflict current use practices are engendering, a question arises as to whether or not the 80% areas could be managed to achieve the 5% tailwater limitation, what the costs would be, and what impact of salt leaching could be anticipated.

In the following three sections, analyses of tailwater control and leaching will be directed toward three questions. The first is the distribution of leaching associated with the NRCE field evaluations and the view this presents concerning an overall leaching strategy. The second is what might be the impacts of end-of-field diking on water demands and leaching under a 5% tailwater control policy. And the third is an examination of attainable levels of leaching under a 5% tailwater control policy.

Existing Leaching Distributions

Once the ***SIRMOD III*** software had been calibrated with the NRCE measurements, simulation of the applied water distributions in each of the nine representative field cases was made. Figures I-1 thru I-9 in Annex I show the results of these simulations.

As shown in Table 1, the ***average*** leaching fractions on the nine NRCE fields ranged from 3% to 20% while the ***distribution*** of leaching over the field lengths, shown in Figures I-1 – I-9, ranged from 0% to almost 30%. Typically, these simulated mid-season irrigations would not provide very uniform leaching over the field length, with particular problems at the inlet and/or outlet. Thus, while the uniformity of the water application is generally high, the leaching is not. One way of increasing leaching is obviously to extend the time of irrigation but this practice would increase tailwater runoff[9]. Another is to irrigate slightly more frequently and apply about one-half inch less per irrigation. The important conclusion from these analyses is that even when average leaching fractions are below the threshold indicated by the salinity in the irrigation water, substantial parts of the field may be adequately leached even during mid-season irrigations. The corresponding distribution of leaching during other irrigations, particularly any pre-plant and post-plant irrigations, would be likely to be more effective in leaching near the upper and lower ends of the field. Consequently, over periods of cropping seasons and cropping rotations, the uniformity of leaching may be substantially different than indicated by simulating the NRCE evaluations.

Simple Blocked-End Border Irrigation

In the second analysis performed with the ***SIRMOD III*** software, a dike was simulated at the downstream end of the field and the inflow and times of cutoff were adjusted to achieve a 5% tailwater constraint. It was further assumed that the average leaching should be at least 5% in order to prevent excessive under-irrigation. A small 200 ft strip of the field at the lower end was simulated with an adjusted slope of 0.0005 in order to increase the intake opportunity time at the downstream end of the field. The results are tabulated in Annex II as Table II-2. The resulting leaching distributions are shown in comparison with the original cases in Figures II-1 thru II-9. It should be noted that diking the downstream end of the field does not completely eliminate tailwater as water may need to be released after a given length of time to prevent scalding.

Taking the NRCE fields as typical of about 50% of the IID service area and making the additional assumption that the field conditions evaluated by NRCE would represent a preponderance of irrigations on fields growing alfalfa and grass, the average cost of diking the lower end of the border and flattening the last 200 feet of the field averages about $13 per acre. This investment would return an average of about 0.6 to 0.7 acre-feet/acre in water savings. The blocked-end control of tailwater does not mitigate the problem of uneven leaching during the mid-season irrigations, although it does move the under-leached region up the field which may have some advantage for leaching during the early season or post-cultivation irrigations. In any event, it is clear that blocking the end of a border to control tailwater within 5% of headgate diversions, based on the NRCE evaluations, would not increase either the area under-irrigated or under-leached. Thus, this alternative for mitigating a decrease in water supply of about 0.6 acre-foot/acre could be made without any impact on crop yields and only a modest investment in land leveling.

Field Re-Design

According the Rhoades' declaration[10], the leaching requirements in the IID service area should average about 8.5%. This figure along with the assertion that tailwater could be limited to 5% of headgate diversions poses the hypothetical question as to whether or not both constraints might exist simultaneously. This question was addressed by simulating the NRCE fields 1-9 under different inflows, cutoff times, and land leveling practices. For this series of simulations, there were four constraints places on the analysis: (1) the end of the fields were assumed to be blocked subject to a scalding protection release; (2) the fields were re-leveled to have the lowest 400-800 feet graded to 0.05%; (3) the average leaching need to be at least 8.5%; and (4) the total water use needed to be less than reported by NRCE. This last constraint was used to test whether or not water conservation would be possible by imposing tailwater constraints as upper bounds and leaching as a lower bound.

Annex III presents the results of these simulations. Table III-1and Figures III-1 – III-9 show that for the NRCE fields both tailwater and leaching constraints can be imposed by adjusting inflow rates, set times, and by leveling the lower end of the fields. The average leaching possible with a 5%

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[9] Tailwater would have to exist for a length of time needed to refill the crop root zone at the end of the field plus the infiltration time needed to add the incremental leaching fraction.

[10] Declaration of James D. Rhoades in Opposition to IID's Motion for Preliminary Injunction..

tailwater constraint is 13% and the water savings would average 0.30 af/ac, although two the fields would require slightly more water if the leaching was allowed to be as high as shown. Adjustments to the inflow time and rate as well as the field configuration to achieve both constraints could be made to lower water requirements, but it would be prudent to exceed the lower bound on leaching by 1-3% to offset the non-uniformity in leaching that is inherent in these mid-season irrigations.

The costs shown in Table III-1 are based on a $0.50 per cubic yard of cut and hauled material. The cuts averaged 0.17 feet (2 inches). These changes will require a small investment to change the field slopes of about $50 per acre.

Two other factors in the re-design of the fields are the sets and the design flow from the IID system. These were modified slightly but are within the range of existing practice. All set times are rounded to quarter-hourly steps for ease in scheduling and ordering water.

Pre-plant, emergence, and late season irrigations are normally less efficient than those during the midseason. Early irrigations tend to have greater deep percolation and later ones higher tailwater. Thus, the results in Annex III are conservative in the sense that higher leaching fractions may be possible over the season and certainly from crop rotation to rotation.

IMPLICATIONS FOR IID MANAGEMENT

An important issue for managing water under a tailwater control strategy is the impact that management and operation of the IID canals and laterals can have on on-farm irrigation performance. A border irrigated farm could be re-designed to achieve high efficiency and uniformity but perhaps would not be operated at these levels unless the headgate deliveries would be steady and made at the proper flow.

A simple illustration can be made to address this issue. If NRCE Field 1 is redesigned to with a blocked end and a flattened slope over the lower 400 feet, it can be irrigated with three sets, each using 13.9 cfs from the IID system. The performance of the irrigation system at the farm level is shown in Table III-1, where resulting irrigations could be made at an irrigation efficiency of about 93% (including 8.5% for leaching), a distribution uniformity of 97%, and a tailwater loss of about 5%. The grower would require about 80 acre-feet less from the IID system, a savings of $1,280 per year assuming a water charge of $16 per af, but would incur about $4,300 in land level costs plus perhaps an additional amount for lost production in the cut areas for a season or two.

If the IID system does not supply this grower with the 13.9 cfs required to optimize irrigation of the borders then the efficiencies may decrease and the costs of the improved water management would not be recovered. Suppose the actual flow rate varied between 25% less than the design flow to 25% more. If the grower is able to adjust set times to make the best use of water given the inflow discharge, the results would be similar to those summarized in Figure 1 below.

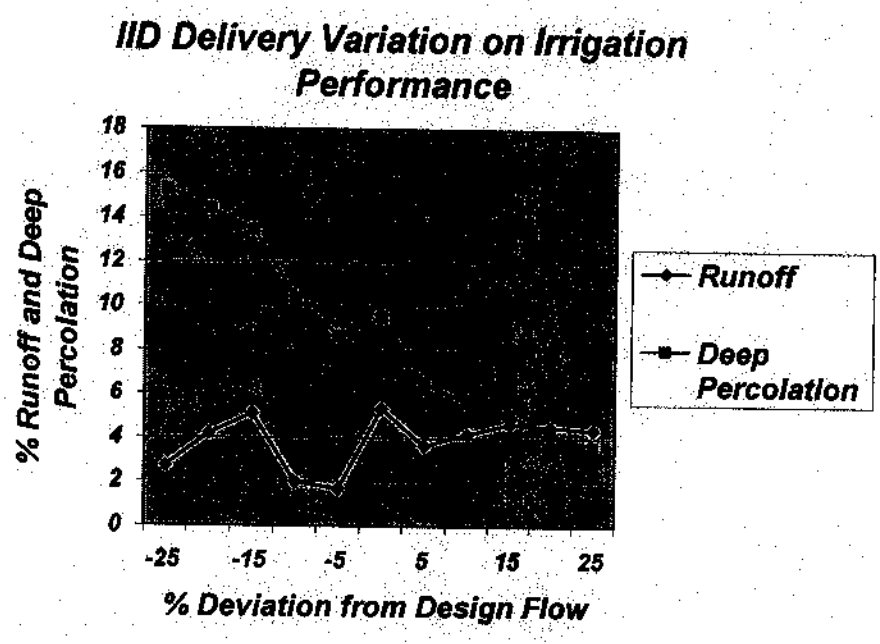


Figure 1.

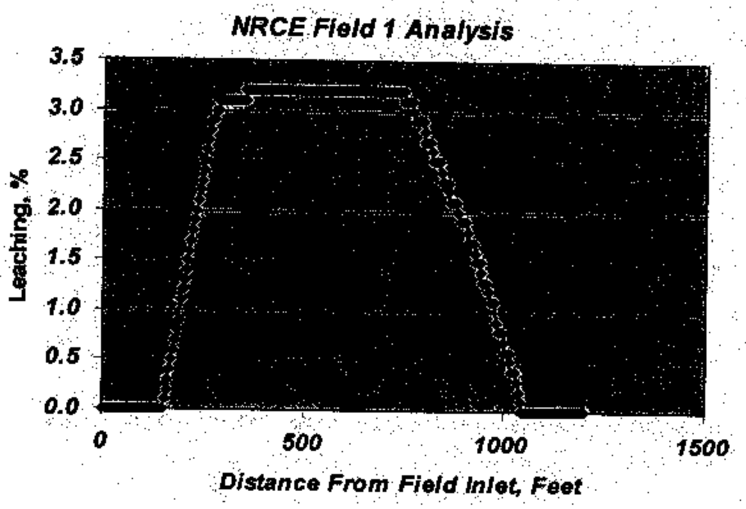
When the IID deliveries fall short of the required flow, the deep percolation, and thus leaching increase proportionately. As the delivered flow increases, the opportunity for leaching decreases. Controlling tailwater to a 5% limit is possible but would require the irrigator to shutoff the inflow at different times. There may be long-term consequences of the high inflows relative to leaching on the field and certainly the water management would require more labor to increase monitoring of water advance.

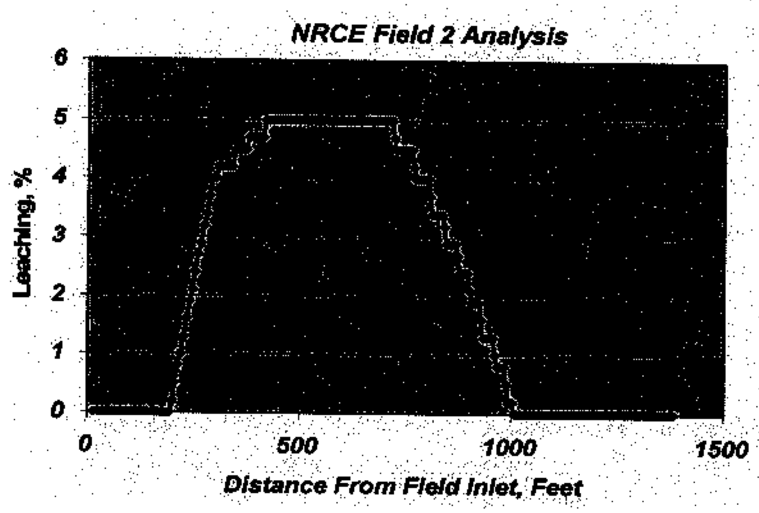
SUMMARY

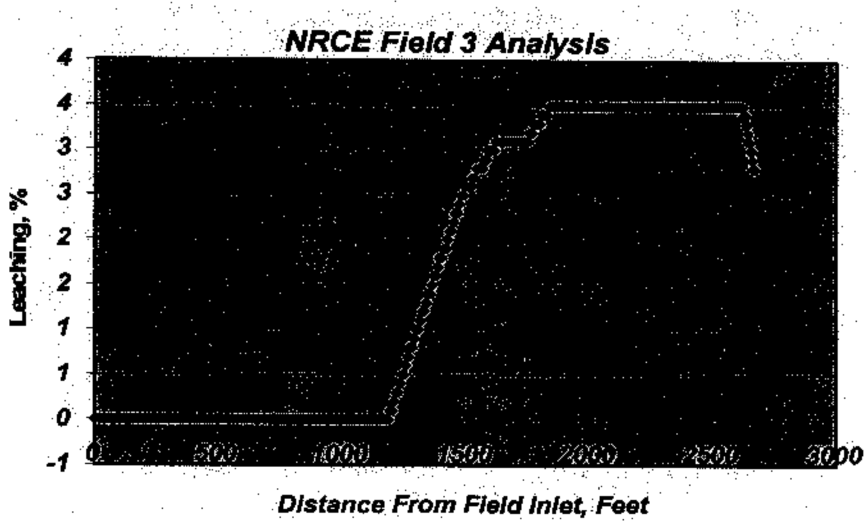
The foregoing analysis of NRCE data with the ***SIRMOD III*** software shows the field evaluations of the ten fields in the IID service area yielded realistic estimates of the on-field irrigation performance during mid-season irrigations of alfalfa and grass in the regions of the heavy soils. There are, however, serious questions regarding the validity of NRCE estimates of soil moisture depletion and soil moisture holding capacity based on three soil samples which appear to have been collected over fields as large as 70 acres. Further, not all evaluation data were presented in the report.

Perhaps the most serious limitations of the NRCE evaluations are: (1) the lack of pre-plant or emergence irrigations; (2) irrigations on the lighter soils; and (3) the furrow irrigation of row crops. These events are typically different than mid-season irrigations because the infiltration rates are substantially higher, the soil surface is rougher, the impedance due to crop growth is less, and the soil moisture depletions may be less. Harold Payne conducted a special field evaluation on February 12, 2003 involving a rather extreme case of light soil, border-irrigate wheat, and poor management. Analyses of these data are given in Annex IV to illustrate the observation that NRCE studies could have been more broadly applicable with a wider range of evaluations.

ANNEX I – LEACHING DISTRIBUTIONS IMPLIED BY NRCE FIELD EVALUATIONS







NRCE Field 4 Analysis

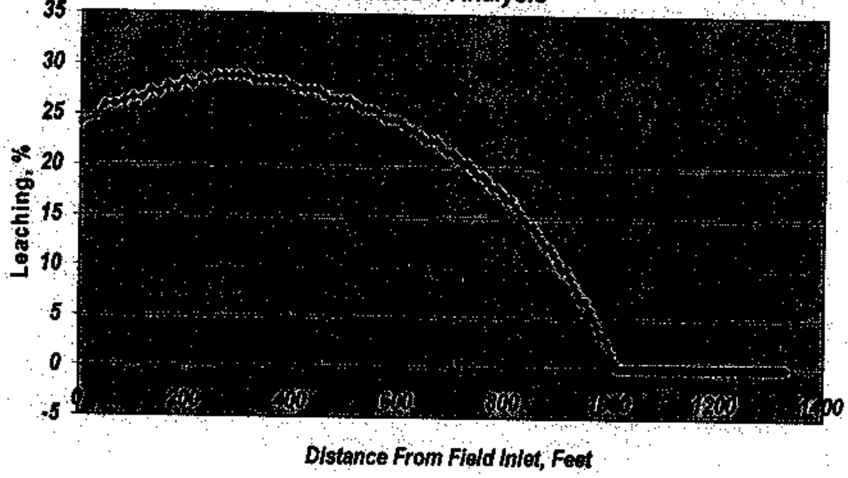
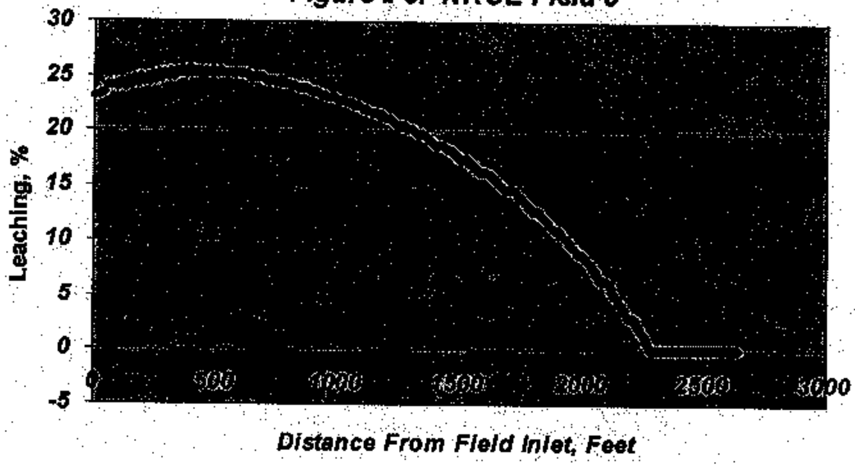


Figure II-5. NRCE Field 5



NRCE Field 6 Analysis

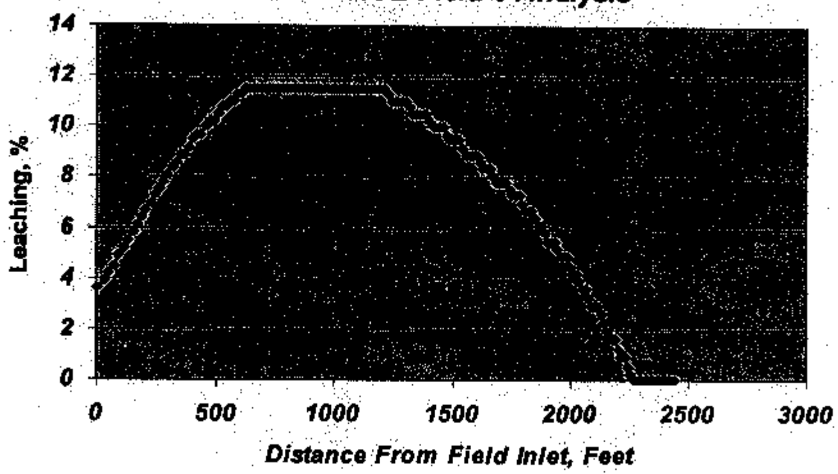


Figure II-7. NRCE Field

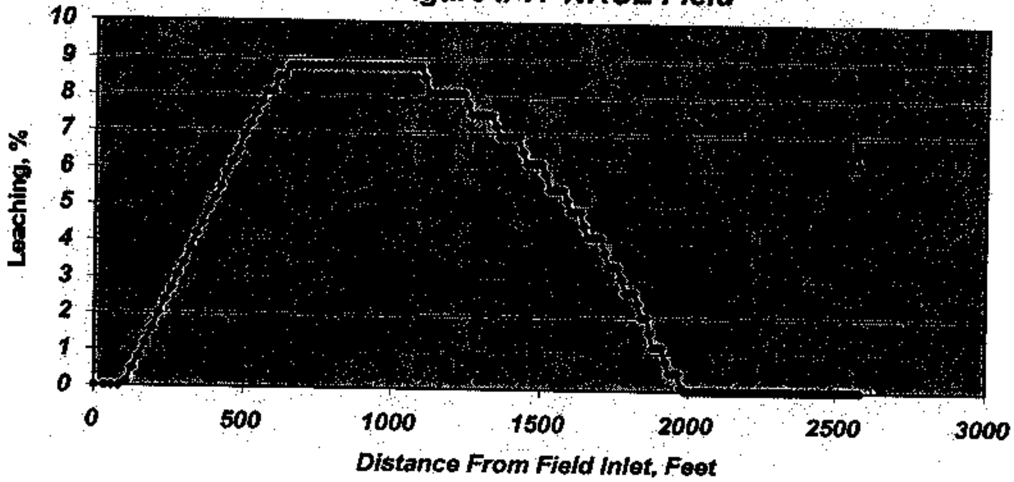
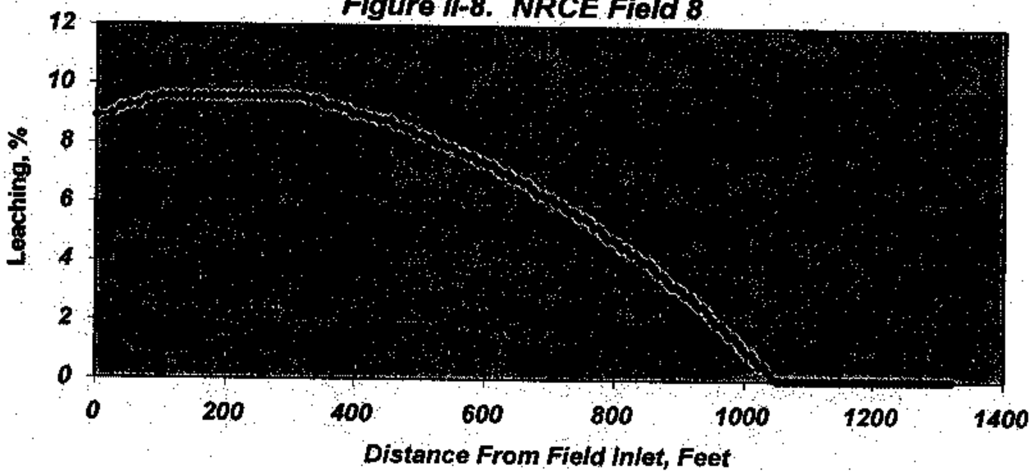
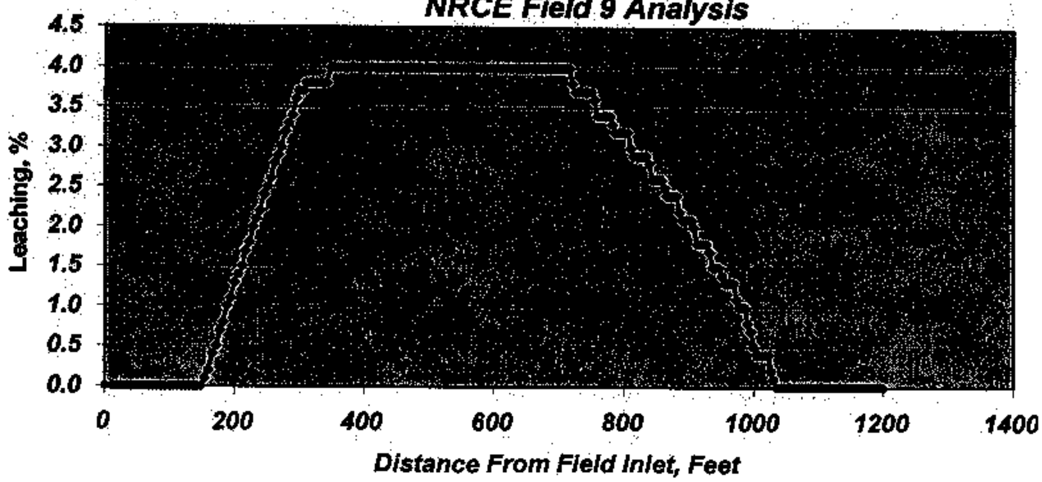


Figure II-8. NRCE Field 8



NRCE Field 9 Analysis



ANNEX II – ANALYSES OF BLOCKED-END AMENDMENTS TO WATER USE AND LEACHING IN THE NRCE EVALUATION FIELDS.

1	5.5	3	3	0.017	94	95	5	6	$19	94
2	3.0	3.5	10	0.043	92	93	4	7	$12	24
3	4.0	3.5	10	0.061	94	94	5	6	$13	53
4	2.75	4.0	10	0.052	92	91	4	11	$18	35
5	17.5	3.5	2	0.0158	93	91	5	8	$6	32
6	5.5	4.2	4	0.05	93	94	4	7	$10	40
7	8.0	5.0	5	0.042	93	89	5	7	$11	87
8	3.0	3.0	8	0.115	94	94	5	7	$17	52
9	13.0	3.0	4	0.0072	93	93	5	6	$10	40

Figure II-1. NRCE Field 1

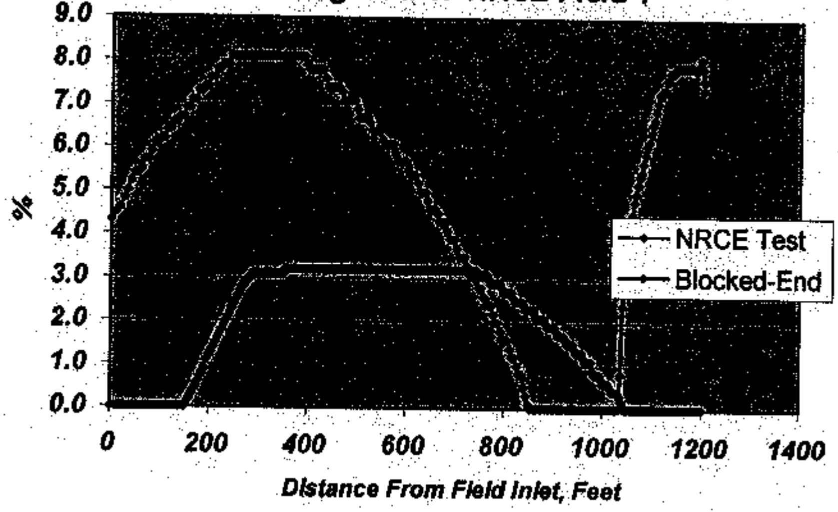


Figure II-2. NRCE Field 2

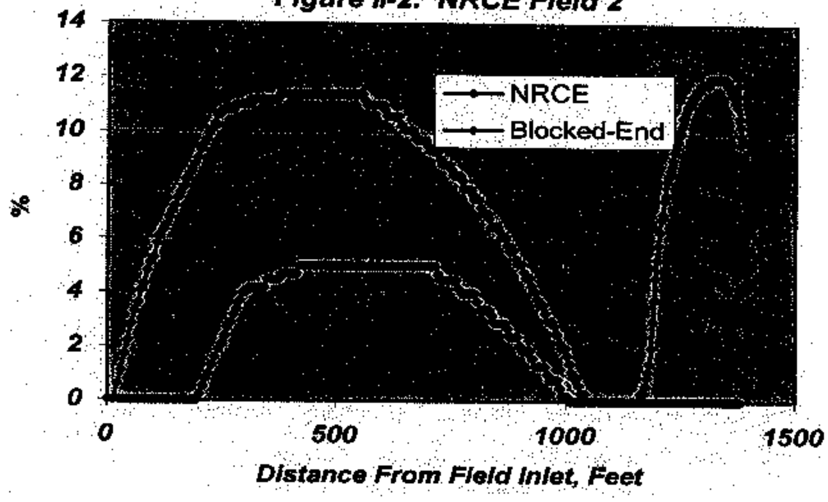


Figure II-3. NRCE Field 3

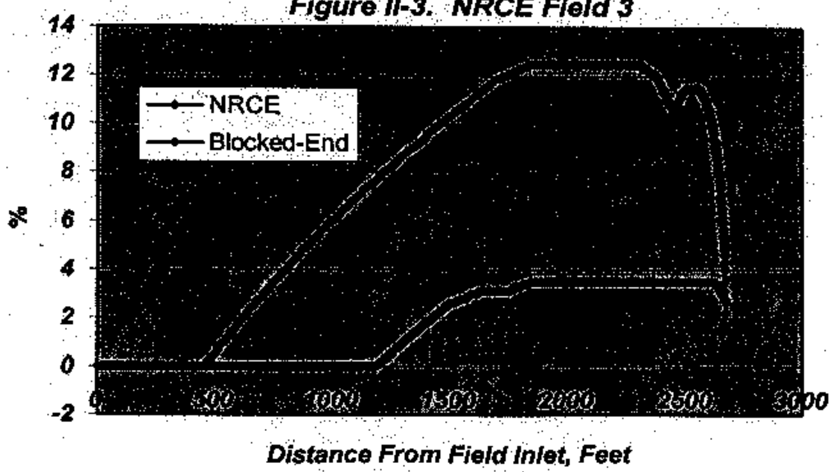


Figure II-4. NRCE Field 4

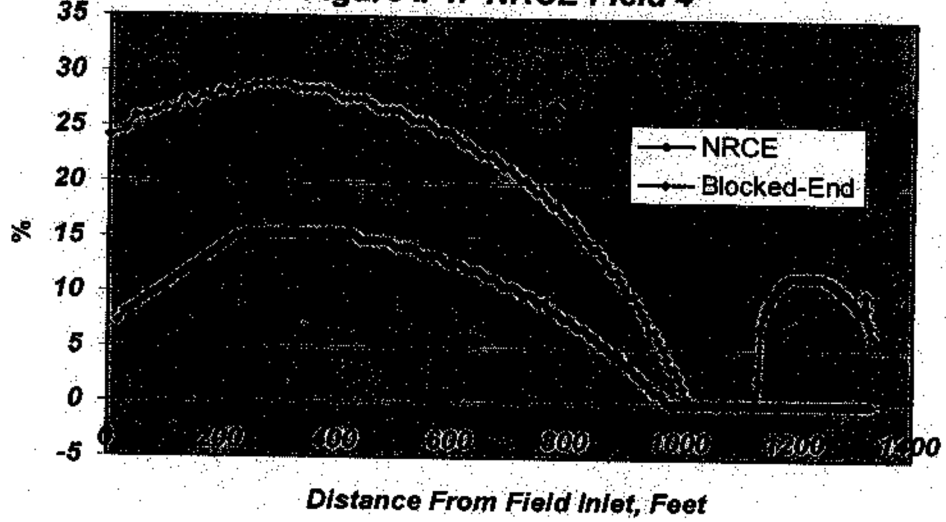


Figure II-5. NRCE Field 5

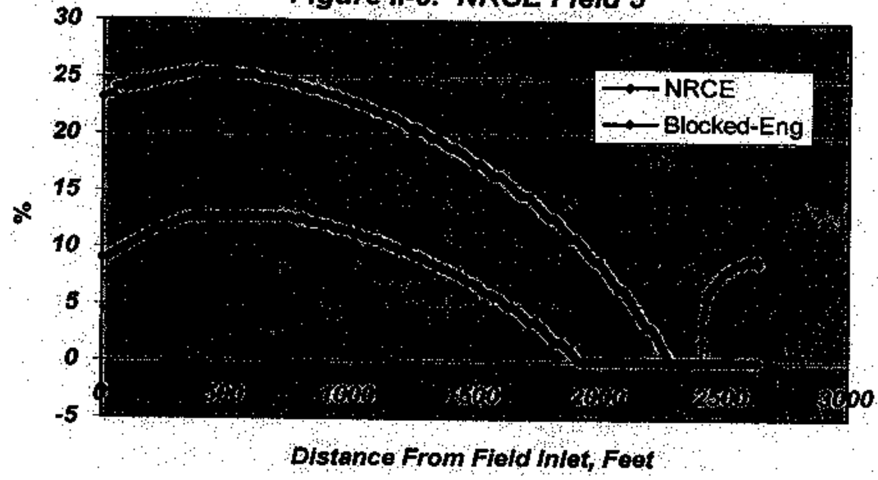
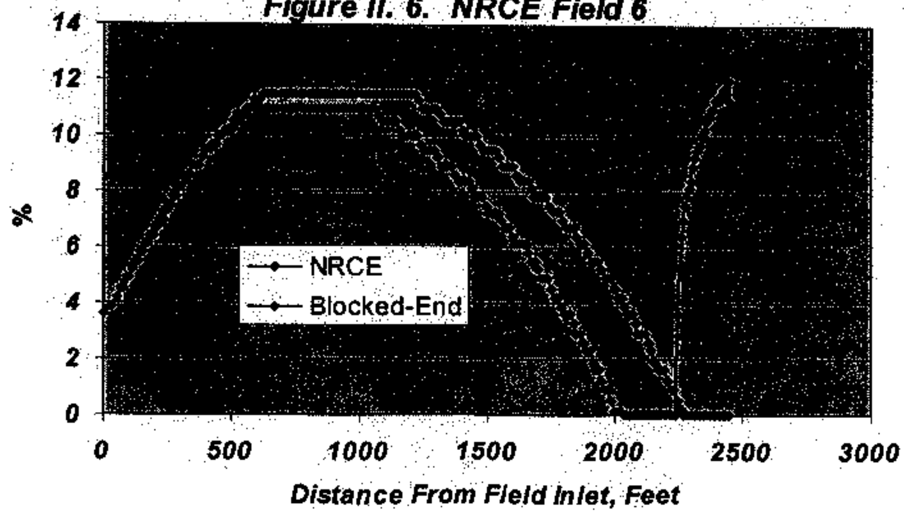


Figure II. 6. NRCE Field 6



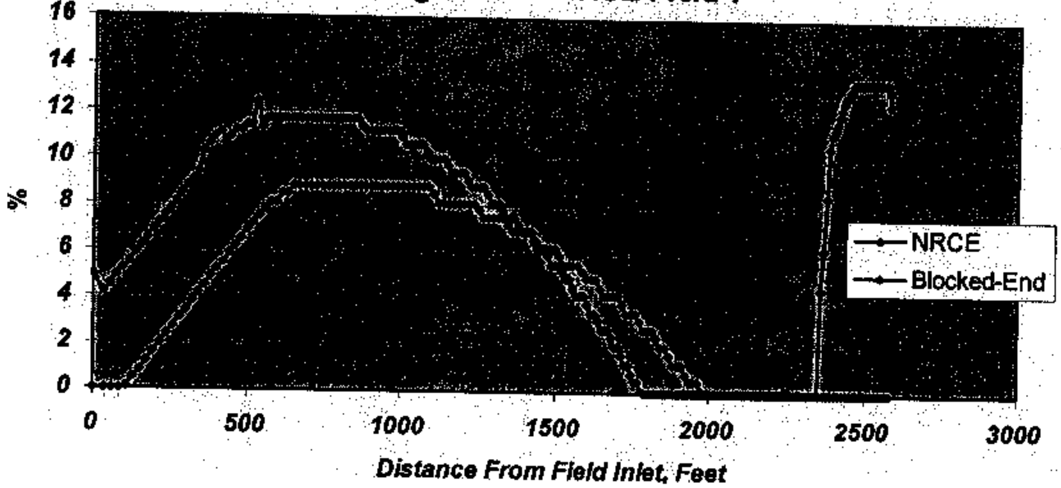


Figure II-7. NRCE Field 7

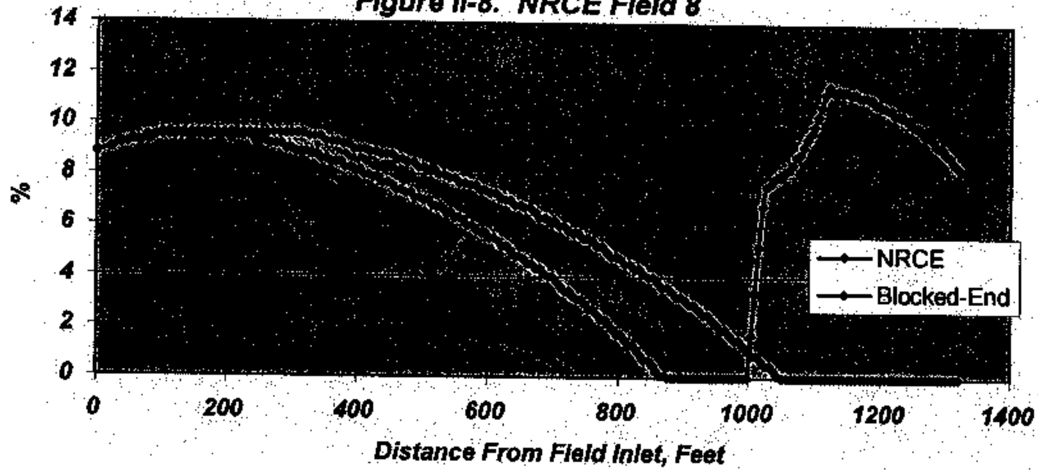


Figure II-8. NRCE Field 8

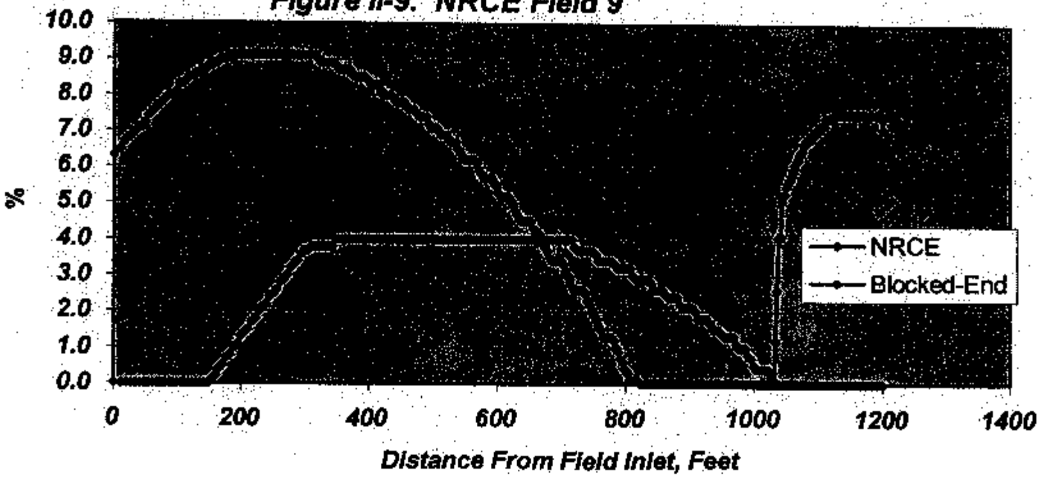


Figure II-9. NRCE Field 9

ANNEX III – *ANALYSES OF RE-DESIGNED BLOCKED-END BORDER PERFORMANCE IN THE NRCE EVALUATION FIELDS.*

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	Change slope of the last 400 feet to 0.0005, block end, and adjust unit flow	3	0.016	93	97	5	10	$4,300	79
2	" "	3.5	0.039	89	96	5	13	$2,800	-11
3	" "	3.5	0.0326	91	98	5	12	$7,200	9
4	" "	4.0	0.05	89	94	3	15	$4,200	12
5	Change slope of the last 880 feet to 0.0005, block end, and adjust unit flow	3.5	0.01925	90	96	5	13	$5,800	15
6	Change slope of the last 400 feet to 0.0005, block end, and adjust unit flow	4.0	0.044	87	94	5	16	$2,600	-5
7	Change slope of the last 700 feet to 0.0005, block end, and adjust unit flow	5	.0403	90	94	5	13	$6,800	47
8	Change slope of the last 300 feet to 0.0005, block end, and adjust unit flow	5	0.093	90	96	5	13	$2,500	28
9	Change slope of the last 400 feet to 0.0005, block end, and adjust unit flow	2.5	9.4	91	98	5	12	$2,300	21

Figure III-1. NRCE Field 1 Analysis

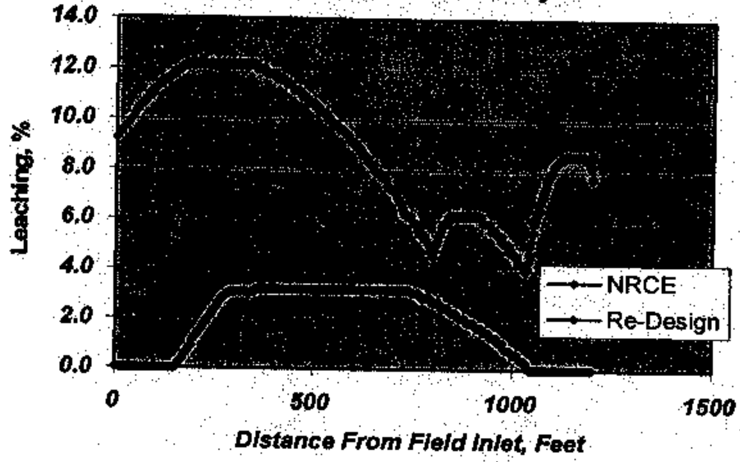


Figure III-2. NRCE Field 2 Analysis

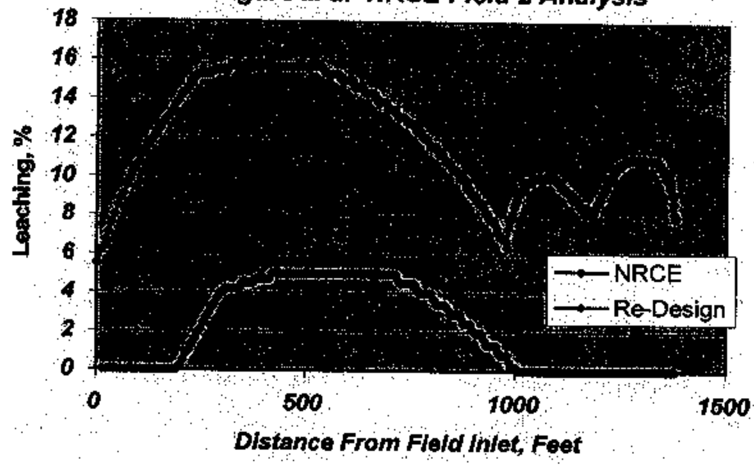


Figure III-3. NRCE Field 3 Analysis

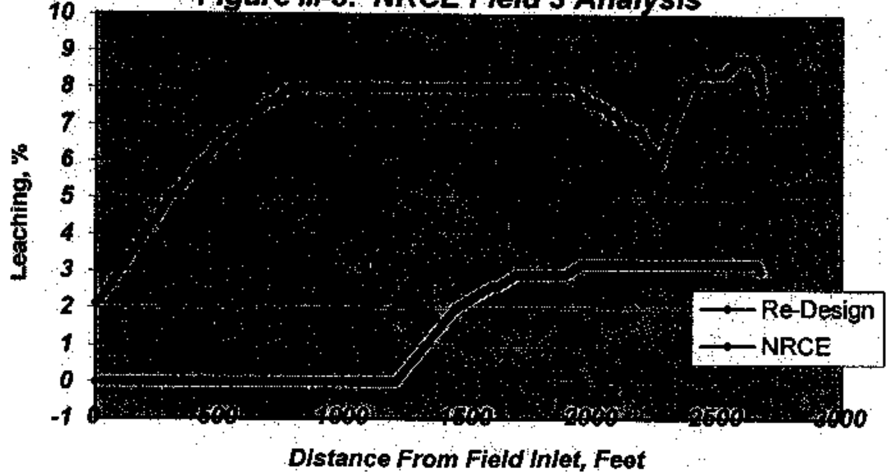


Figure III-4. NRCE Field 4 Analysis

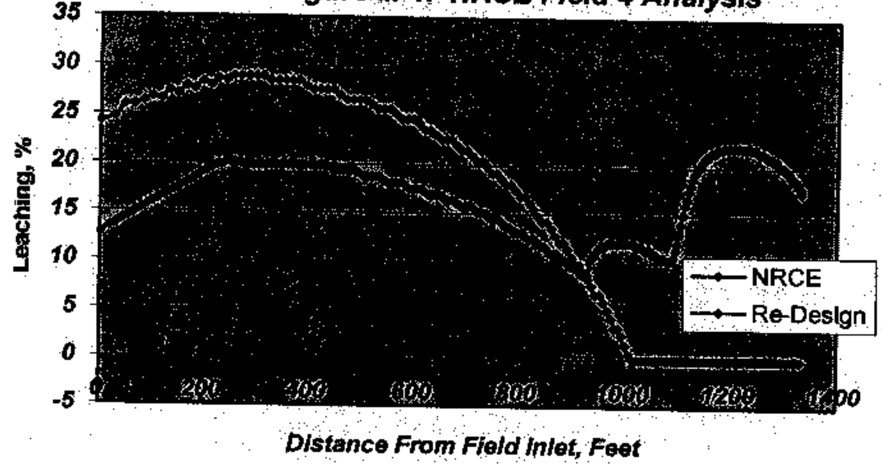


Figure III-5. NRCE Field 5

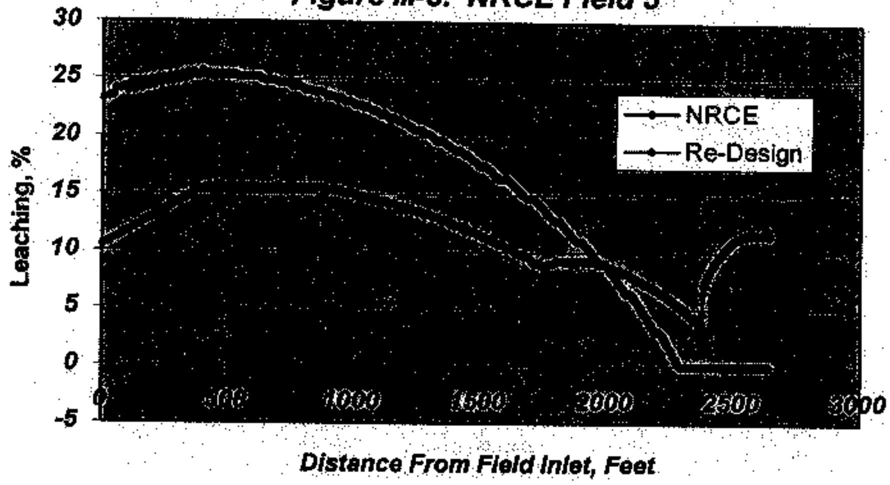


Figure III-6. NRCE Field 6 Analysis

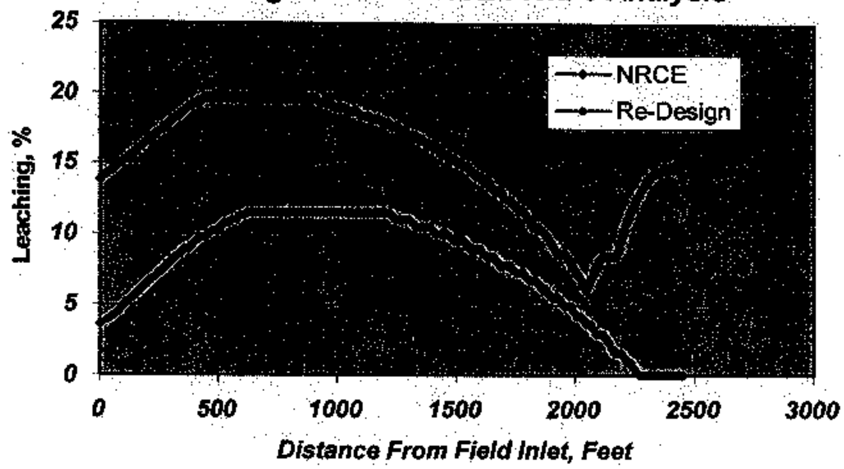


Figure III-7. NRCE Field

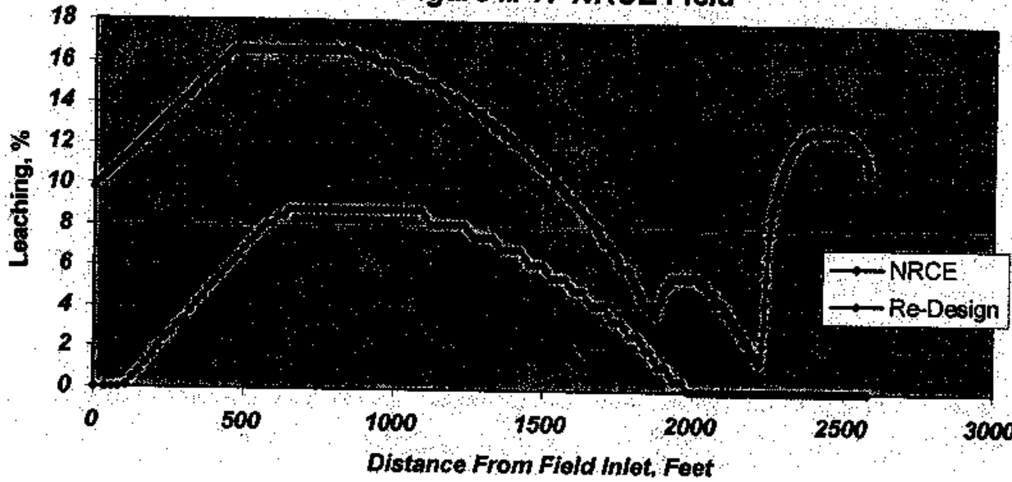


Figure III-8. NRCE Field 8

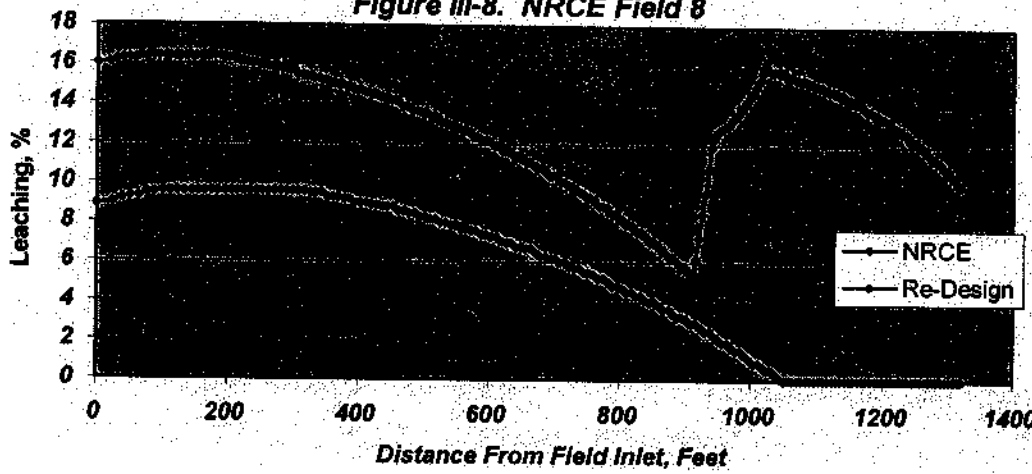
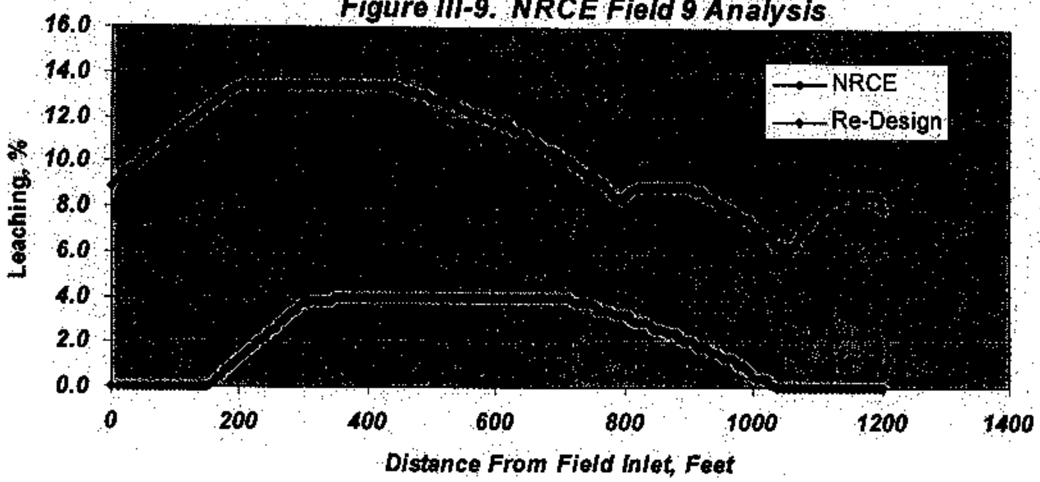


Figure III-9. NRCE Field 9 Analysis



ANNEX IV – ANALYSES OF HAROLD PAYNE'S FIELD EVALUATION

ANTECEDENTS

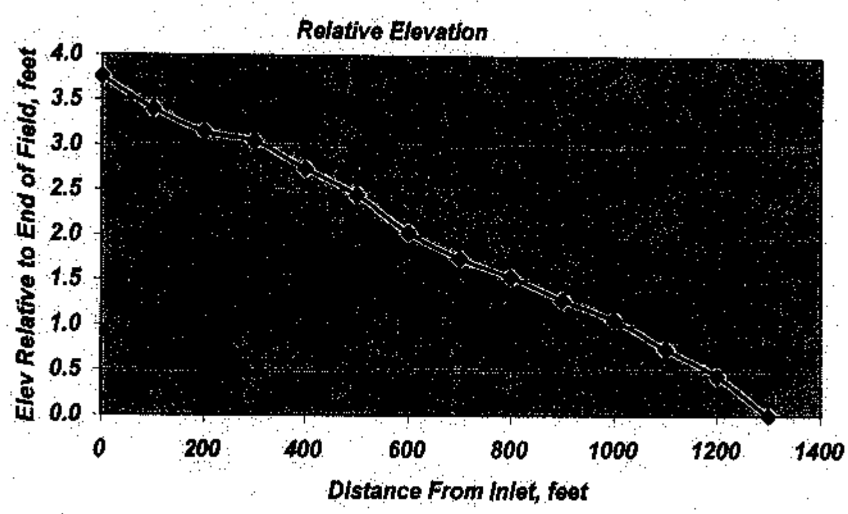
The NRCE field evaluations were somewhat selective relative to soil type giving rise to a concern that the reported irrigation efficiencies were biased toward a higher value than might be characteristic of the entire IID service area. To illustrate the problem in the minds of the MWD technical team reviewing the NRCE study, a separate evaluation was conducted by Harold Payne, one of the MWD consultants on the team. This evaluation occurred on February 12, 2003. Data listed below and field conditions described are those reported to the writer in a personal communication February 25, 2003.

METHODOLGY

Prior to the evaluation, the writer and Mr. Payne discussed the data necessary of input ot the ***SIRMOD III*** software, as well as the field procedures for collecting it. This evaluation was then conducted according to the same standard methodologies used by NRCE. In addition, an extensive interview was conducted with the irrigator for insights on general irrigation practices and preferences.

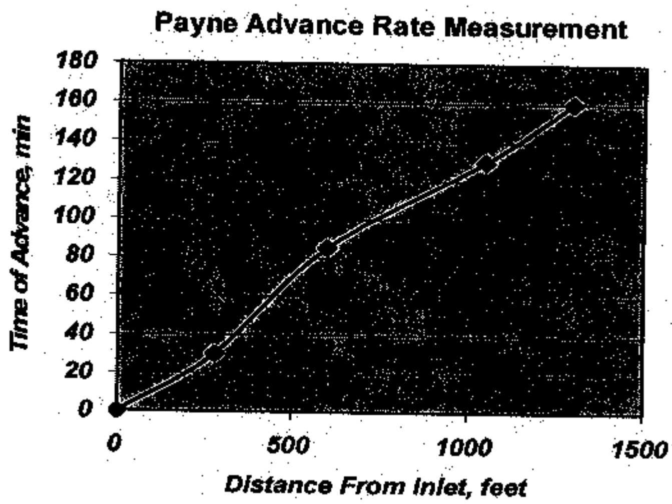
SITE AND TEST DESCRIPTON

The evaluation was conducted on two borders 1300 feet long characterized by a measured slope of 0.00289 as shown in the figure below. The soil according to USDA classification and personal inspection was a sandy loam which had estimated soil moisture holding capacity of 1.2 inches per foot of depth and a basic infiltration rate of about 1 inch/hr. The borders were planted to Durum wheat which has sprouted and reached the 6^{th} leaf stage about 2 inches in height.



The irrigation evaluated was the first post-plant irrigation. A flow of 0.043 cfs/ft was applied to the field for 220 minutes resulting in an average application of 5.7 ac-in/ac. Soil samples collected prior to the irrigation and evaluated by the "feel method" indicated the soil moisture depletion was about 1.38 inches.

Advance rate measurements, summarized in the figure below, are relatively uniform – an observation noted by NRCE in their evaluations.



SIMULATION RESULTS

The SIRMOD III software uses an extended form of the Kostiakov-Lewis equation for infiltration:

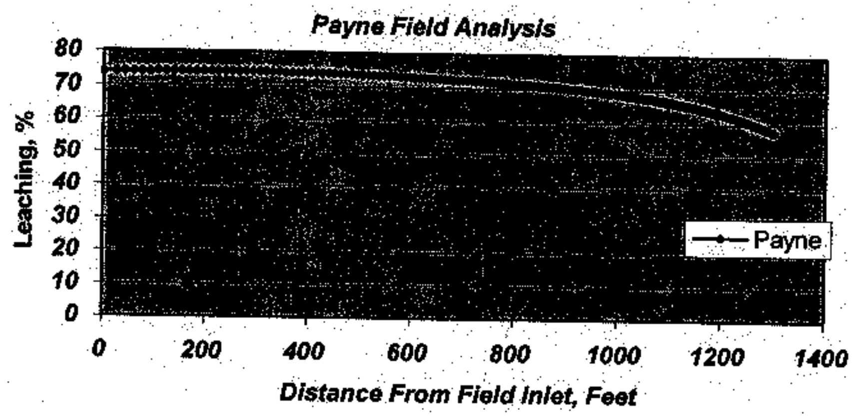
$$z = k\tau^a + f_0\tau + c \qquad (1)$$

Payne estimated that the basic intake rate, $\mathbf{f_o}$, would be about 1.0 in/hr. Using this figure and the measured advance time, the values of **k** and **a** were determined to be 0.0356 ft/min^a and 0.244 respectively. The **a**-value is somewhat low for a sandy loam soil indicating the $\mathbf{f_o}$ value of 1.0 in/hr (0.00139 in/min in the software) is too high. Nevertheless, this value was used in the analyses that follow. The **c**-value representing cracking volume was set to zero. The parameter **z** is the applied depth at a specific location in feet and the $\boldsymbol{\tau}$ is the intake opportunity at the location in minutes.

The software also uses a form of the Manning Equation to describe friction losss a s the flow passes over the field. For the conditions Payne described, the writer assumed a n-value of 0.025.

Based on these assumed parameters, the software predicted an advance time of 165 minutes as compared to the 160 min that were observed. The field tailwater predicted was 8% of the field deliveries as compared to 7% measured at the tailwater box. Payne estimated the application efficiency at 24% and the software yielded a value of 26%. It is assumed that the leaching fraction is 8.5% as indicated earlier, the irrigation efficiency computed by the software would be about 29%. A plot of the estimated leaching is shown below.

As seen the management of this irrigation was very poor as measured by efficiency. The high leaching that occurred would have moved the nitrogen fertilizers the grower had applied to a depth beyond the roots of the wheat and thus the cost of this irrigation would be quite high. This evaluation nevertheless shows what can happen in the lighter soils if proper field design and efficiency water management are not applied.



RE-DESIGNING THE FIELD

It is perhaps useful to demonstrate via the simulation model what optimal field design and water management practices could achieve in this extreme example. Following the analyses of previous sections, the software was used to simulate the field in which the end was blocked to eliminate tailwater (subject to a scald release if necessary) and the lower end was flattened to improve uniformity of water distribution. In addition, the borders were had a simulated width of 100 feet rather than the existing 150 foot borders. The inflow to the field could be reduced to 10.8 cfs and two borders irrigated simultaneously or increased to 16.2 cfs from the existing 14 cfs and irrigate three 100 foot borders simultaneously. The irrigation efficiency would increase from 28% to about 86%, thereby reducing the water requirements accordingly.

The re-designed field would have an average deep percolation of 15% yielding an leaching distribution as shown below. This is of course an illustrative example. In practice, the grower would want an irrigation system that achieved a leaching requirement closer to 8 or 9% which would require flattening more of the field and/or shortening the length of run for the irrigation water. A field with this type of soil is generally more efficiently irrigated with furrows than with borders and more advance management schemes like surge flow are possible.